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Study of General Features of Particle Production in p-p Collisions at 400 and 100 GeV

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Exposures : i) 50,000 pictures of 400 GeV protons, ~15 tracks/picture.
ii) 50,000 pictures of 100 GeV protons, ~15 tracks/picture.

Detector : 30-inch Hydrogen Bubble Chamber with about 32 kG field (highest possible)

In the past, the only way one could obtain information on particle production at primary energies above a few tens of GeV was through the studies carried out with cosmic-rays. Two major limitations of these investigations have been the low fluxes of primary particles and the lack of precise knowledge of the primary energy. Although such studies have led to a great deal of useful information, on the basis of which general qualitative models[1] of high energy interactions have been constructed, attempts at dynamical description of the interaction at these energies

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have been inhibited by the inherent lack of precision in cosmic-ray experiments. It is hoped that with coming into operation of the ISR at CERN and accelerator at NAL, USA, this lack would be partly rectified.

The operation of the ISR at CERN has already begun to yield data on characteristics of particle production at equivalent lab energy of 1000-1500 GeV. Considerable amount of data on p-p collisions in the region 10-30 GeV has accumulated during the last decade or so. There is thus a gap in the intermediate energy range. We propose to carry out a study of p-p collisions at 400 GeV and 100 GeV and thus partly bridge this gap.

Very general ideas concerning the structure of hadron-hadron collisions have been recently put forward by Feynman[2)] and Yang et al.[3)]. Likewise, Van Hove[4)] has suggested the use of "longitudinal rapidity" as a variable to highlight the pionization particles. These suggestions provide a useful framework for analysis of data. We hope to exploit these in the study proposed here.

1. Aim of the Experiment

We propose to carry out a fairly detailed study of particle production in p-p collisions at two energies, namely 400 GeV and 100 GeV, which differ by as much as a factor of 2 in the C. M. system.

This should enable us also to study energy dependence of interesting features. In order to give an indication of what we hope to achieve, we list below some promising possibilities.

1.1 Test of Scaling Hypothesis

Recent preliminary results[5] on angular distribution of secondary particles in the C. M. system, ($35^{\circ} < \theta^{*} < 90^{\circ}$), from ISR emulsion experiment at C. M. energy of $\sqrt{s}$ = 52 GeV (equivalent lab energy of 1400 GeV) disagrees with Scaling prediction using the 19 GeV/c $pp \rightarrow \pi^{-}$ + (anything) Scandinavian Collaboration data[6] On the other hand, ISR results of Ratner et al.[7] indicate that Scaling law holds for particles with rather large momenta in the C. M. system, for $x = p_L^{*}/p_{max}^{*}$ between 0.1 and 0.3. Although some evidence[6,8] has been reported in literature for the validity of the Scaling hypothesis even at 19-30 GeV/c, we believe that these are not sufficiently sensitive tests. We propose to test Scaling in an unambiguous manner in the region of 100-400 GeV.

As indicated in 2 below, for both 400 GeV and 100 GeV, the momenta of secondary particles emitted in the backward hemisphere in the C. M. system will be low enough in the L-system to be measured reasonably precisely. We shall therefore be able to obtain the distributions of longitudinal momentum in the C. M. system, (p_L^{*}) at 400 GeV and 100 GeV. This would enable us to test the validity of Feynman's

Scaling hypothesis at these energies, e.g., if Scaling has set in at 100 GeV one expects the absolute number of particles per unit p_L^* at $p_L^* = 0$ to be constant, independent of the primary energy.

1.2 Target Fragmentation

The work of Chen et al. [9] indicates the setting in of the limiting behaviour of the target fragments [3] at relatively low energies (around 20 GeV/c). However, the fact that such a limiting behaviour extends up to energies in the range of tens of thousands of GeV, was already suggested in the early sixties from cosmic-ray data [1]; it was argued that in the absence of such a limiting behaviour, the ratio of positive to negative muons in cosmic-rays could not have stayed constant up to energies of $\sim$1000 GeV. The nature and composition of the target fragments was only qualitatively established. With an accelerator exposure of the type asked for, this can obviously be done with more precision.

1.3 Pionisation Component

One hole in the hitherto available cosmic-ray information concerns the properties of the so-called "pionisation" process. There is no doubt what-so-ever that majority of particles produced in high energy interactions have relatively low energies in the C.M. system.

Whether these particles form a distinct component separated from the fragmentation products is not definitely established. Cosmic-ray information on this point is rather meagre.

The ISR results of Ratner et al.[7] and those of ISR emulsion experiment[5] on angular distribution in the C. M. system for $35^{o} < \theta^{*} < 90^{o}$, if confirmed, would lead one to believe, that created particles fall into two groups[1,10,11], namely, (i) the pionisation particles, those with $x \lesssim 0.1$, resulting from fireballs moving slowly in the C. M. system (these particles would violate Scaling) and (ii) those with $x > 0.1$ resulting from baryon isobars (these would exhibit Scaling behaviour). We propose to study these features at 400 GeV and 100 GeV by examining in detail, the angular distribution, the longitudinal momentum distribution and the longitudinal rapidity distribution.

The 19 GeV data[12] on C, M. angular distribution indicates that the effective lorentz factor of the fireball (or multi-fireballs) in the C. M. system, γ_f^* is close to unity ($\simeq 1.1$). The cosmic ray study of angular distribution in p-p collisions in the energy range 70-600 GeV seems to suggest $\langle \gamma_f^* \rangle \simeq 1.5 - 1.6$, with little variation with primary energy[13]. A fit to the above mentioned preliminary ISR emulsion results indicates $\gamma_f^* \simeq 1.5$ at 1500 GeV. Thus, it appears that γ_f^* increases with energy at low energies and then attains some kind of saturation at 100 GeV or so. The experiment proposed here would enable us to obtain more reliable information on this interesting feature.

1.4 Transverse and Longitudinal Momentum Distributions

We hope to carry out a detailed study of the distributions of transverse momentum, p_T, and longitudinal momentum in the CM-system, p_L^*, at 400 GeV and 100 GeV. In particular, we would like to see whether factorisation of $f(p_L^*, p_T)$ into $F(p_T). G(p_L^*)$ is a good approximation.

Analysis of lateral distributions of cores in extensive-air-showers seems to indicate[14] that there exist particles which have abnormally large transverse momentum (several GeV/c). Although study proposed here is at far lower energies, it is, nevertheless, worth looking into these possibilities.

1.5 Baryon-antibaryon Production

There is evidence[15,16] that at air shower energies the pionization component or rather the particles produced with moderate energies in the C.M. system - contain a significant fraction (over 15%) of stable massive particles, presumably baryon antibaryon pairs. If one assumes that kaon production does not increase dramatically from 30 GeV to 1 TeV, the analysis[17] of emulsion data indicates strongly that baryon-antibaryons should constitute around 20% of all created particles at about 1-5 TeV primary energies. We would like to investigate whether the increase in the antibaryon production cross-section has already set in at 100-400 GeV.

In a bubble chamber experiment, one can easily distinguish positive baryons and negative baryons (antiprotons, etc.) from positive pions and negative pions respectively, for momenta less than about 1 GeV/c. If the baryon-antibaryon production is appreciable, this study may yield some useful results.

The consequences of a possible copious baryon-antibaryon production would be very interesting. For example it is conceivable that these created baryons are produced in various excited states with as great a probability as do the target baryons. If so, the dominant fraction of the created particles would be associated either with the fragmentation of the colliding particles or with the fragmentation of the created baryons and antibaryons. Therefore we propose to examine how often a produced antiproton is dynamically associated with a pion - in other words look for isobars like $\overline{N}^*_{33}$ amongst the created particles.

We hope also to be able to get some information on kaon and hyperon production by carrying out observations on K^o and Λ.

1.6 Other Information

The above gives some idea of the type of results we hope to obtain from the experiment proposed here. In addition, this work is expected to yield a variety of useful results, e. g. on multiplicity, inelasticity, p-p inelastic cross-section, etc.

2. Experimental Considerations

The number of pictures requested in this proposal will yield nearly 20,000 inelastic events within useful volume at each of the two primary energies.

Since p-p collision is symmetric in the CM-system, we can get complete information on particle production by carrying out measurements on particles emitted backwards in the CM-system; these particles would have relatively low momenta in the L-system. One can get a rough idea about the momenta of particles which would have to be measured from the following argument. At 400 GeV, the lorentz factor of the CM-system is $\gamma_c = 14.1$. The median angle in the L-system, which roughly demarks the particles emitted in the forward and backward directions in the CM-system, is given by $\theta_M = \tan^{-1}(1/\gamma_c) = 4.0^\circ$. The average momentum of a particle having $\theta = 4^\circ$ will be $\langle p \rangle = \langle p_t \rangle / \sin \theta = 0.35/\sin 4^\circ = 5$ GeV/c. Thus it is reasonable to assume that a good majority of the particles emitted backward in the CM-system will have momenta less than about 10 GeV/c in the L-system.

The overall error in momentum for HBC is given to a first approximation by the expression

$$\left(\frac{\Delta p}{p}\right)^2 = \frac{2.5}{H^2 L} + \frac{3.5\,p^2}{H^2\,L^4}\,\epsilon^2$$

where H is in kG, L in cm, p in GeV/c and ϵ in microns is the random error on a single point measurement in chamber space. Thus for 30" chamber with 32 kG field, assuming $L = 35$ cm. and $\epsilon = 100\,\mu$m, we find that for a 10 GeV/c particle the error on momentum will be around 5%, which is quite acceptable for the type of analysis planned here.

Since a small percentage of particles emitted with $\theta^* \simeq 180^\circ$ are expected to have $\theta < 4^\circ$, we plan to carry out measurements on all particles within $\theta < 4^\circ$ too.

Thus, it is clear that the procedure outlined here will enable us to study the CM-system characteristics of particles in p-p collisions at 100 GeV as well as 400 GeV in a fairly reliable manner.

3. Facilities for Analysis

The Bubble Chamber Group at TIFR consists of 9 physicists, 5 of whom have had experience in analysis of bubble chamber pictures at the University of Wisconsin, USA, (A. Subramanian and R. Raghavan), Northwestern University, USA, (P. K. Malhotra), University of Minnesota, USA, (Banvir Chaudhary) and CERN, Switzerland, (S. N. Ganguli), It may also be pointed out that a majority of the nine physicists have been active in the field of experimental high energy physics at accelerator and/or cosmic-ray energies, for over a decade. We have had a long tradition of work, both theoretical and experimental in the problem of particle production at high energies. Some of the papers written by members of the Bubble Chamber group on this subject are listed in the Appendix.

The hardware at present consists of 3 measuring and 3 scanning machines. These machines can handle both 35 mm and 70 mm films. The main computational needs are met by the Institute's CDC-3600 computer. This facility is capable of processing about 50,000 events per year.

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APPENDIX

Some Publications of the members of the TIFR Bubble Chamber Group in the area of High Energy Collisions of Hadrons

R.R. Daniel, N. Kameswara Rao, P.K. Malhotra and Y. Tsuzuki
Some Characteristics of Inelastic Proton-Nucleon Collisions Produced by Protons of Energy 6.2 BeV in Nuclear Emulsions
Nuov. Cim. 16, 1, 1960

P.K. Malhotra and Y. Tsuzuki
Analysis of Some Nuclear Interactions of Energies 10^{12} - 10^{14} eV/nucleon
Nuov. Cim. 18, 982, 1960

Yash Pal and T.N. Rengarajan
Observations on Neutral π-Mesons Produced in Nuclear Interactions of 24 GeV Protons with Carbon Nuclei
Phys. Rev. 124, 1575, 1961

S. Lal, Yash Pal and R. Raghavan
Nuclear Interactions at 20 to 150 GeV in Carbon
Nuclear Physics 31, 415, 1962

P. Babu, R. Cowsik and Yash Pal
Neutral Pion Production by 17 GeV Negative Pions in Carbon
Nuov. Cim. 29, 785, 1963

R.R. Daniel, N. Durgaprasad, P.K. Malhotra and B. Vijayalakshmi
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Nuov. Cim. 30, 791, 1963

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A Study of the Production of γ-rays in High Energy Nuclear Interactions Part II: A Study of Individual High Energy Interactions in Graphite
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